Our findings demonstrate a possible behavioral outcome of a visual system with massive retrograde connections between category-sensitive and more primary visual areas [5,12] and suggest a reassessment of theories that eschew top-down conceptual influences on visual selection [13,14]. The present results make it clear that visual perception depends not only on what something looks like, but also on what it means.

Supplemental data

Supplemental data are available at http://www.current-biology.com/cgi/content/full/18/10/R410/DC1

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Saccadic latency during electrical stimulation of the human subthalamic nucleus

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High-frequency electrical stimulation of the subthalamic nucleus ('deep brain stimulation') has rapidly become a popular method for treating patients with Parkinson's disease [1], and is now widely recognised as one of the most effective long-term treatments. So far, the neural mechanisms underlying its effectiveness have been elusive. However, measuring saccadic latency — the time taken to look at a sudden visual stimulus — seems a promising approach. Latency varies randomly from trial to trial, and analysis of the resultant statistical distributions

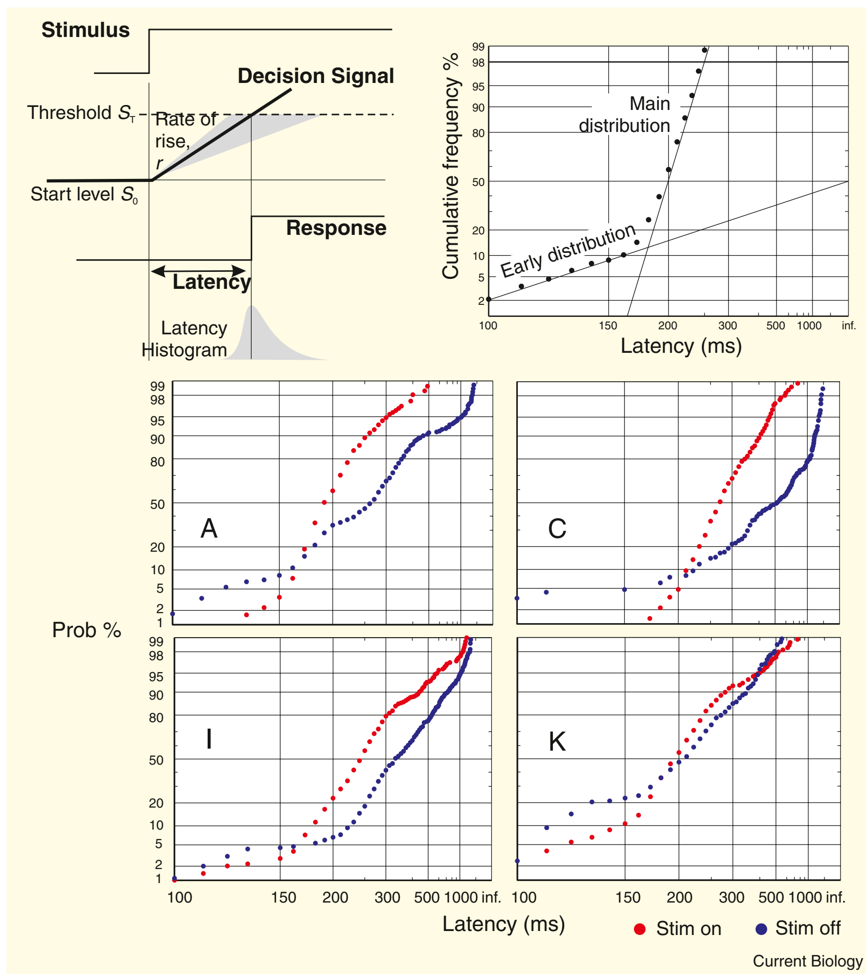

Figure 1. Saccadic latency distributions.

Above: in the LATER model, a decision signal rises linearly from its initial value of S_0 at a rate r until it reaches a threshold level S_T, at which point a response is initiated. Because r varies randomly (following a normal distribution) on different trials, the time to reach threshold, and thus the latency, also varies randomly. Consequently, if reciprocal saccadic latencies are plotted as a cumulative histogram, using a probit ordinate, a straight line will be obtained (right). However, under certain conditions more saccades with very short latencies are observed than the model would predict: these generally lie on a different line of shallower slope that intersects it. Below: reciprobit plots for four representative patients, comparing all trials for which the subthalamic stimulation was on, with all trials in which it was off. The effect of stimulation is to reduce median latency, the proportion of early responses, and the degree of irregularity of the distributions.

provides information about the parameters of the underlying decision-making mechanisms of the brain. Measurement of these parameters can then provide a sensitive and non-invasive way of quantifying the effects of clinical interventions, and providing information about the underlying neural mechanisms. In a group of Parkinson patients with electrodes previously implanted in the subthalamic nuclear complex, we found that bilateral electrical stimulation dramatically reduces the time taken to initiate a saccade. The effect on the distribution of latency corresponds to an increase in the rate of accumulation of the underlying decision signal, suggesting that stimulating this region specifically enhances the gain of descending pathways through the basal ganglia that contribute to saccadic initiation.

There are several advantages in using saccadic latency as a quantitative measure of cerebral performance. It is sensitive and non-invasive, and with modern, micro-miniature portable equipment, several hundred saccades can be measured in a matter of minutes. This enables precise estimates of the parameters underlying the random trial-by-trial variation that is characteristic of all reaction times, and can be described economically by means of the LATER model (for details see the Supplemental Data available on-line). This approach has previously been successfully applied in monitoring the development of Huntington's disease and Parkinson's disease [2,3], and can be related to the growing body of work on the underlying neural decision mechanisms, which involve widespread areas of the brain that include parietal cortex, the frontal and supplementary eye fields, the basal ganglia and superior colliculus [4,5].

Figure 1 shows cumulative distributions of saccadic latency to unexpected 10° step displacements of a visual target for four of our eleven patients, comparing all trials with stimulation on and all with stimulation off, as reciprobit plots. For each of the 11 patients, stimulation markedly reduces latency, seen as a shift of the curve to the left. In many patients there is also a tendency for the early component to be reduced, and for the curves to lose the bumpy irregularities characteristic of Parkinson patients [3], though this is difficult to quantify.

In the absence of medication, stimulation very significantly reduces mean latencies (Figure 2: mean 286 ms ± 36.4, compared with 380 ms ± 44.7: paired t-test $p = 0.0092$). By contrast, in the absence of stimulation, medication resulted in an insignificant increase in mean latency (mean 452 ms ± 75.3; paired t-test: $p = 0.13$).

In the LATER model, reduction in latency can occur in two ways: either by increasing the mean rate of rise of the decision signal, or by altering the starting level or the threshold, and these produce characteristic changes in the observed latency distributions [6]. Using a log-likelihood ratio test to compare these two models, we found that the results across all patients very significantly ($p << 0.001$) favoured the hypothesis that the effect of stimulation is to increase the rate of rise of the LATER decision signal.

In the absence of medication, stimulation produced a highly significant improvement of the standard clinical UPDRS motor score (mean difference 23.6; t-test $p << 0.001$) which significantly correlated with the reduction in latency ($R = 0.67$; $p = 0.025$). Medication alone produced a smaller improvement that was not statistically significant (mean 8.6, $p = 0.084$; $R = 0.23$, $p = 0.49$).

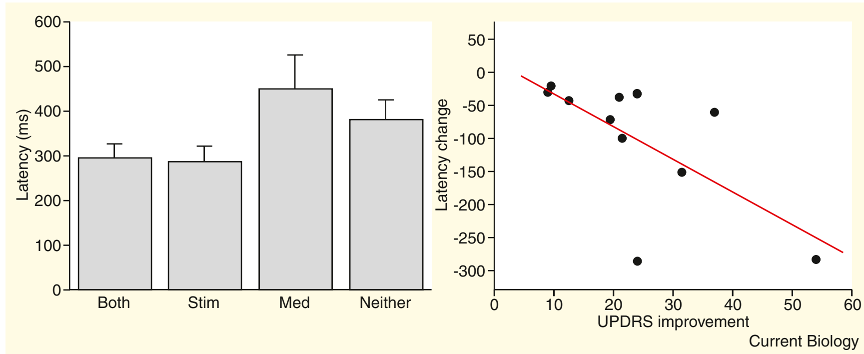

Figure 2. Mean saccadic latencies.

Left, median latencies across all patients, comparing all possible combinations of stimulation and medication: Both, Stimulation only, Medication only, and Neither. Error bars show 1 SEM. Right, comparison of the reduction of median latency caused by electrical stimulation (in the absence of medication) with improvement in the total UPDRS score under the same conditions. The regression line corresponds to $R = 0.67$, $p = 0.025$.

Thus, saccadometry appears to provide a sensitive and objective measure of the effects of subthalamic stimulation in Parkinson patients, correlating well with conventional, subjective, evaluation of motor impairment. The effects are far too large to be explicable by alterations on movement execution time. In terms of the LATER model the most economical explanation is that they result from an increase in the mean rate of rise of the underlying decision signal, which could in turn be the result of an increase in gain of the underlying mechanism.

The subthalamic nucleus has long been known to enjoy a special relationship with the oculomotor system. In particular, it sends a powerful glutamatergic projection to the substantia nigra pars reticulata, a region containing neurons that decrease their activity in association with saccades [7], and in turn generate disinhibition of the superior colliculus [8], part of a pathway descending from the cortex via the caudate nucleus and globus pallidus, which has an essential role in the initiation of saccades.

As high frequency electrical stimulation of the subthalamic region is known to decrease the activity of its output nuclei [9], a natural interpretation of our findings is that this enhances both the descending facilitation that passes from the cortex to the colliculus via the basal ganglia, thus increasing the mean rate of rise of the decision signal, and also the tonic background inhibition that normally suppresses unwanted early responses. Nevertheless, the effect of subthalamic nucleus stimulation on basal ganglia output is likely to be more than a 'simple' inhibition [10] and in this respect the effect on saccadic latencies might involve a multifaceted mechanism.

Supplemental data

Supplemental data are available at http://www.current-biology.com/cgi/content/full/18/10/R412/DC1

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Self-awareness affects vision

Eric L. Smith[1], Marcia Grabowecky[1,2] and Satoru Suzuki[1,2]

What we see can be influenced by attention [1,2] and concurrent sensory inputs from other modalities, such as accompanying sounds [3,4], but can high-level mental factors such as states of self-awareness systematically affect vision? Because associative learning is a fundamental property of the nervous system, we hypothesized that different states of self-awareness might selectively enhance perception of specific visual patterns based on experiential associations. Perception of self-faces provided an ideal test case because of the common experiential associations between perception of mirrored and un-mirrored self-faces and unique states of self-awareness. We found, consistent with the typical experience of looking at a mirrored self-face in privacy and an un-mirrored (for example, photographed) self-face in the company of others, that recognition of mirrored self-faces was superior when self-awareness was internally directed, whereas recognition of un-mirrored self-faces was superior when self-awareness was socially directed. As mirrored and un-mirrored faces are highly similar (as in Figure 1B), our results indicate that states of self-awareness affect visual perception with considerable pattern resolution. This has the intriguing general implication that, when a specific state of self-awareness frequently coincides with visual perception of specific patterns, the mental state and visual processing may become associated so that evoking that state of self-awareness selectively enhances visual perception of associated patterns.

When you look at yourself in a mirror, you are typically alone, privately examining your mirrored (left–right reversed) appearance, and your self-awareness is likely to be internally directed to your immediate percepts, including body sensations. This might result in an association between the visual processing of a mirrored self-face and a state of internally-directed self-awareness. In contrast, when you look at your un-mirrored face in a photograph or video, you are often in the company of other people (to whom you show the photograph or video), and your self-awareness is likely to be socially directed (for example, thinking about how others think of you). This might result in an association between the visual processing of an un-mirrored self-face and a state of socially-directed self-awareness. If visual processing is selectively associated with concurrent states of self-awareness in this way, recognizing your mirrored face should be easier when your self-awareness is internally (compared to socially) directed, whereas recognizing your un-mirrored face should be easier when your self-awareness is socially (compared to internally) directed.

To induce an internally-directed state of self-awareness, we instructed participants to focus on their breathing as a bodily sensation; to induce a socially-directed state of self-awareness, we instructed participants to think about their strengths and weaknesses, as people are typically concerned about how others think of them in social situations (see Supplemental data available on-line for experimental details and control data).

In experiment 1, participants saw mirrored self-faces, un-mirrored self-faces, and other people's faces. The task was to press one button when a self-face was presented and to press another button when someone else's face was presented. Mirrored self-faces were recognized faster when self-awareness was internally (compared to socially) directed, whereas un-mirrored self-faces were recognized faster when self-awareness was socially (compared to internally) directed (Figure 1B; significant interaction, $F_{1,23} = 8.26$, $P < 0.01$).

In experiment 2, we determined whether states of self-awareness influenced the strength (in addition to the speed) of self perception. To vary the strength of 'selfness' of the faces, we created intermediate morphs between the participant's self-face and a celebrity's face. The task was to press one button when the participant detected his or her self-face and press another button when he or she detected the celebrity's face. Stronger self perception would result in increased self responses